The cognitive basis of dyadic cooperation in corvids: a neurorobotics model

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PURPOSE

A NUMBER OF STUDIES SHOW THAT DYADS OF CORVIDS ARE ABLE TO COLLABORATE TO SOLVE COOPERATIVE PROBLEMS (SUCH AS THE "LOOSE STRING" TASK). HOWEVER IT'S STILL UNCLEAR WHICH SPECIFIC COGNITIVE SKILLS CORVIDS RELY ON TO COLLABORATE EACH OTHER.

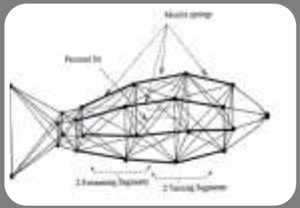
THEORETICAL PURPOSE

- **Shed light on what might be the conditions that contribute to the emergence of cooperation behaviors in corvids and what are the underpinning mechanisms. Do they need a communication channel? Or do they just see and take in consideration the actions of their companion?**

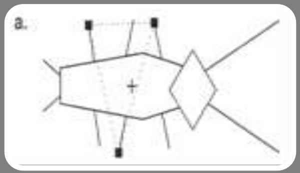
BIO-ROBOTICS

BIOLOGICALLY INSPIRED ROBOTICS PROPOSE TO DEVELOP ROBOTS WITH CHARACTERISTICS SIMILAR TO THOSE OF NATURAL ORGANISMS.

Webb designed and implemented successfully, an autonomous robot that can reproduce the behavior of a phono-tactical cricket [Webb, 1993, 1994].



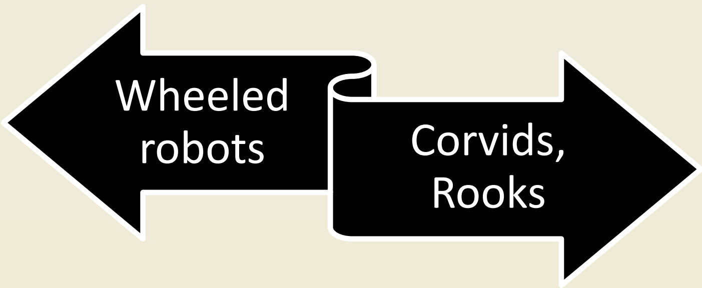
Demetri Terzopoulos and his team, from the University of Toronto, was particularly interested in the simulation of robotic fish, which learn to swim independently [Terzopoulos, Tu, Grzesczuk, 1994] .



Randy Beer developed a simulation of robots able to walk in a manner similar to some insects [Beer, 1995].

METHODOLOGICAL APPROACH

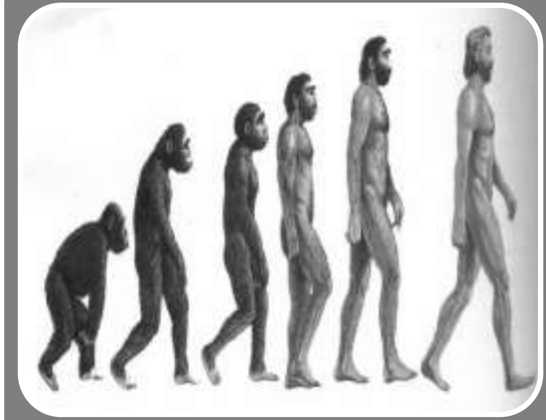
WHEELED CORVIDS



In this approach we use **Artificial Intelligence** and **Robotics** tools that belong to **Evolutionary Robotics** discipline to build self-organizing intelligent systems that are able to simulate animal behaviour .

[Nolfi, S., & Floreano, D. (2000) ***Evolutionary Robotics: The Biology, Intelligence, and Technology of Self-Organizing Machines (Intelligent Robotics and Autonomous Agents)*****, MIT Press, Boston].**

EVOLUTIONARY ROBOTICS



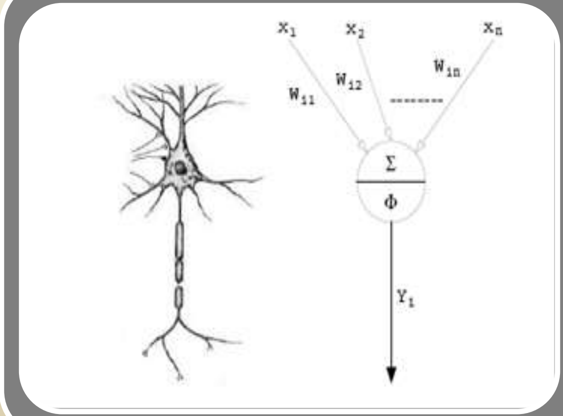
Genetic Algorithm

1) Generate an initial population of random control systems (phenotypes).

2) Reproduction of phenotypes associated with best genotypes in terms of fitness.

3) Random mutation of genetic material.

4) Replay of phase 2) and 3) to obtain the desired performance.

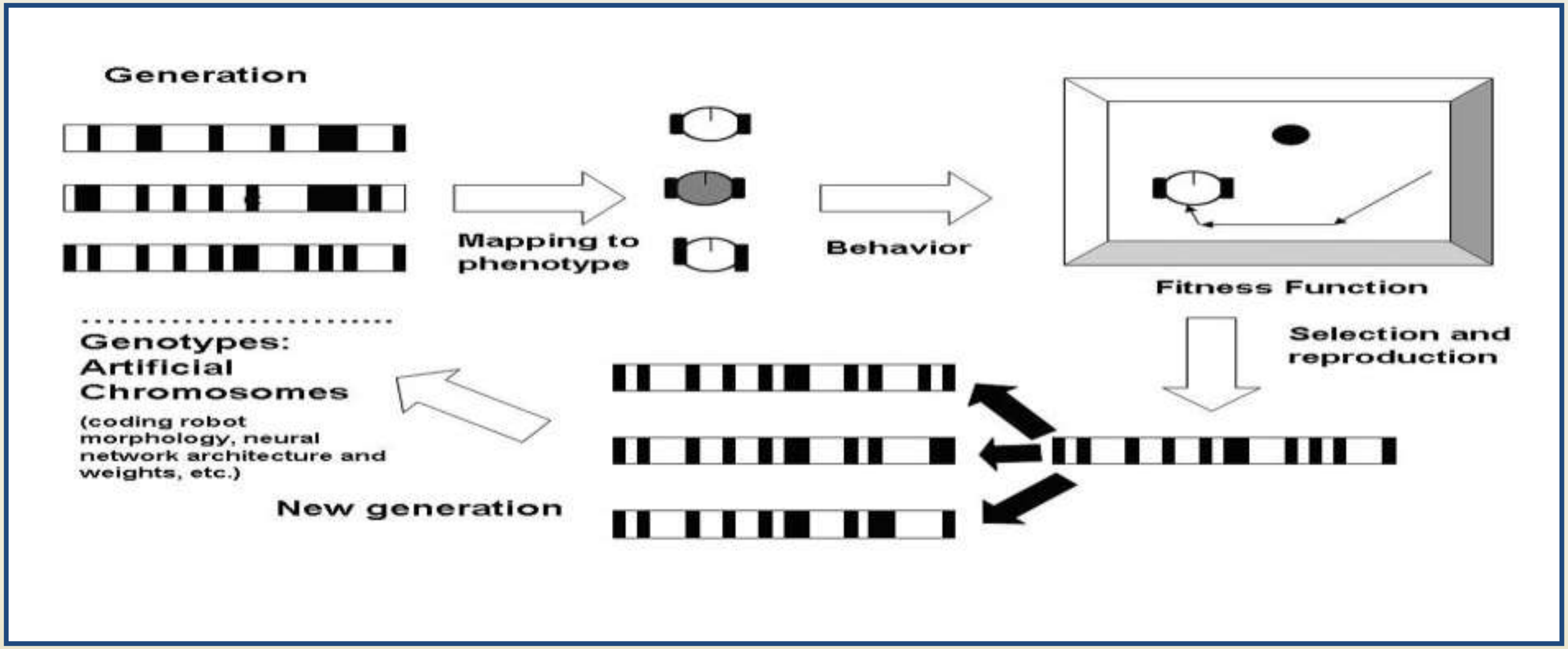


Control neural network

- Floreano and Mondada [1994] were among the first to have used a genetic algorithm for real-time evolution of neural networks that control a small mobile robot.

- Genetic algorithm generate and evolutionary neural network that can solve the required task.

EVOLUTIONARY ROBOTICS



[Ponticorvo M., Walker, R., Miglino O. (2006), *Evolutionary Robotics as a tool to investigate spatial cognition in artificial and natural systems*. In Loula A.C., Gudwin R., Queirz J.,*Artificial Cognition Systems,* Idea Group, Hershley, PA

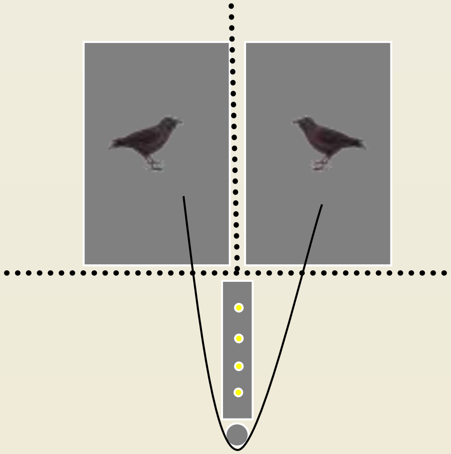
Models in EVOLUTIONARY ROBOTICS

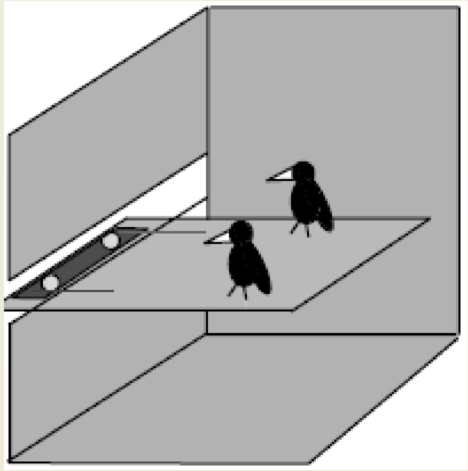
- **Idea Models** : Evolutionary techniques are used to reproduce and general phenomena
- **Data Models** : Evolutionary techniques reproduce quantitative observations of animal behavior in well-defined experimental set-ups.

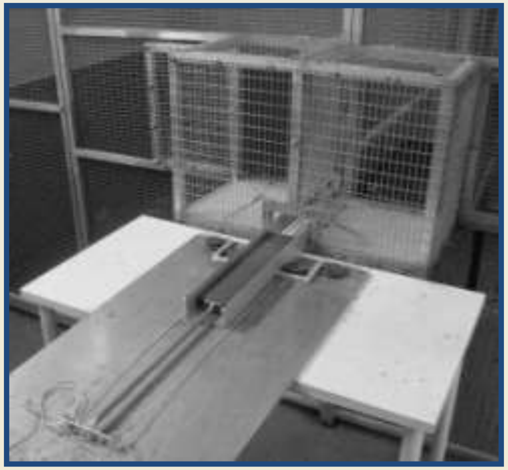
IN OUR APPROACH WE ESTABLISH A STRONG LINK BETWEEN PHENOMENON AND TASK DERIVED FROM EXPERIMENTS ON ANIMAL BEHAVIOUR IN ORDER TO GET INSIGHT FROM THIS KIND OF DATA RECIPROCALLY. FOR THIS REASON WE MODEL EXPERIMENTAL SET-UPS, THAT HAS BEEN WIDELY USED IN ANIMAL BEHAVIOUR LITERATURE.
FOR EXAMPLE WE CAN TRY TO COMPARE WHAT HAPPENS IN CORVIDS COOPERATION WITH WHAT HAPPENS IN ROBOTS COOPERATION.

WELL-DEFINED SETUPS FOR CORVIDS COOPERATION :

THE LOOSE STRING TASK





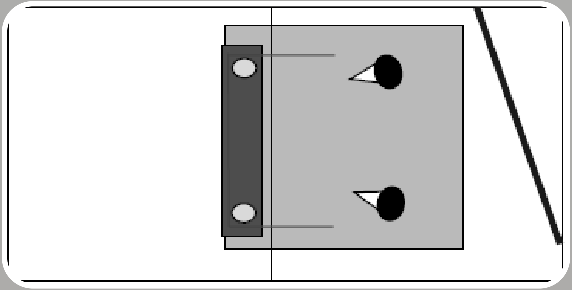


<u>PURPOUSE</u> : UNDERSTANDING WHETHER COOPERATION IN ANIMALS IS UNDERPINNED BY THE COMPLEX COGNITIVE ABILITIES THAT CHARACTERIZE COOPERATION IN HUMANS, SUCH AS PERCEPTION OF THE ROLE AND INTENTIONS OF THE COLLABORATIVE PARTNER OR MORE COMPLEX COMMUNICATION FORMS. IN ORDER TO DO THIS, TWO MEMBERS OF A DYAD ARE TRAINED TO PULL A STRING TO REACH A REWARD. IN THE PAST THE TASK HAS BEEN PERFORMED SUCCESSFULLY BY CHIMPANZEES **[Seed, A.,N., Clayton, N.,S., Emery, J., N.,, *Cooperative problem solving in rooks(Corvus frugilegus),* Proceedings of the royal society]**

The loose string task

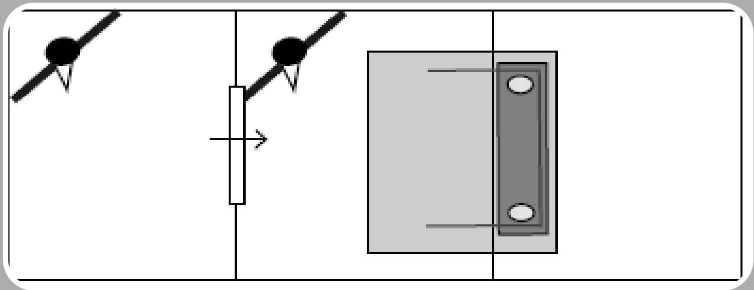
The experiment is divided into two phases.In a first phase, the agents, for example, corvids such as rooks are trained separately to pull the string which allows the bird to get the food by itself. In the second cooperation phase, the two birds could get the reward only if they pulled the string at the same time. Moreover a second and a third experiment ("delay test" and "choice test") was performed to investigate whether or not corvids had an understanding of the need of a partner for effective cooperation by seeing whether they could delay acting on the apparatus while their partner gained access to the test room .

Experiment n .1



All pairs of corvids was able to solve spontaneously the experiment by coordinating their movements and employing valuable cooperative alliances.

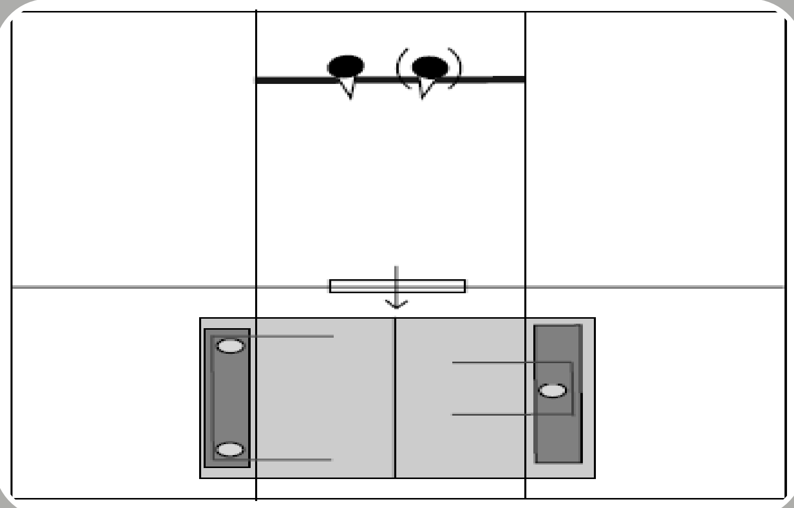
Experiment n .2



Delay Test : The one-way flap was released by the experimenter once the birds were in the test room. In this way it's possible to verify whether rooks waits the other one for the time necessary to enter in the testing room.

The loose string task

Experiment n .3

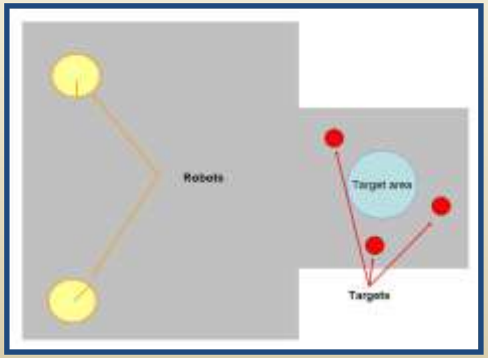


Choice Test : when tested alone, the birds should have preffered to pull the single apparatus because it wasn’t possible to get food from the double apparatus. When tested with their partner they should attempted to coordinate their actions and pull in the double apparatus.

All the subjects failed the task of the experiment n.2 and n.3, that was instead performed successfully by the chimpanzees

COOPERATION IN CORVIDS : STATE OF ART

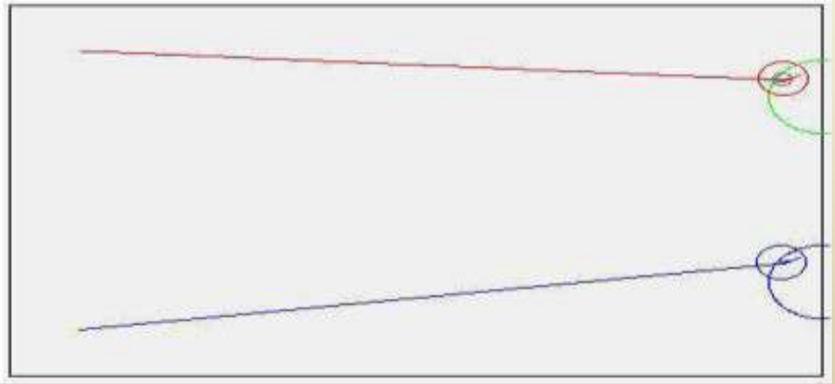
IN A **FIRST EXPERIMENTAL SETUP** TWO ROBOTS E-PUCK ARE SIMULATED INTO AN ARENA WHERE THEY ARE INITIALLY PLACED ON A WIDE CORRIDOR. ONCE THE ROBOTS HAVE REACHED THE GREAT CENTRAL TARGET AREA, IT IS REMOVED AND THREE SMALLER TARGETS ARE PLACED IN THE CORRIDOR. IN ORDER TO ACCOMPLISH THE TASK, ROBOTS HAVE TO DRIVE TOWARDS ONE OF THREE TARGETS. THIS SETUP IS DERIVED BY THE "LOOSE STRING" TASK AND REPRESENTS A SITUATION IN WHICH THE ROBOTS SHOULD COORDINATE THEMSELVES/COOPERATE TO GET A REWARD. **[Miglino, O., Ponticorvo, M., Donetto, D., Nolfi, S., Zucca, P. Cooperation in corvids: a simulative study with evolved robot. In Atti del Convegno WIVACE, 2008]**

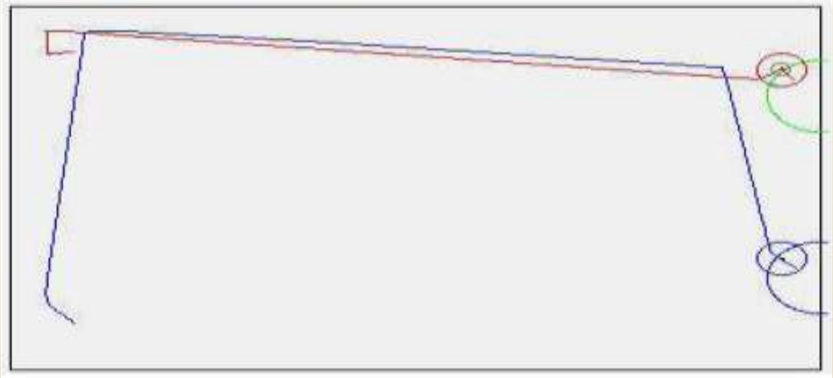


BY EVOLVING, WITH E-R TECHNIQUES, DYADS PROVE TO BE ABLE TO ACCOMPLISH THE TASK, SHOWING AN EFFICIENT BEHAVIOUR. **RESULTS SHOW THAT COOPERATION BETWEEN ROBOTS IS REGULATED BY SOCIAL INTERACTION BETWEEN ROBOTS, WITH COMMUNICATION AS A MEDIUM.** THE EMERGENCE OF COMMUNICATION LEADS TO A COORDINATED COOPERATION BEHAVIOR THAT IS SOMEWHAT SIMILAR TO COOPERATION OBSERVED IN NATURAL ORGANISMS AS CORVIDS.

COOPERATION IN CORVIDS : STATE OF ART

In a **second experimental setup** two robots e-puck situated in a rectangular arena with two target areas, are evolved for the task of reaching areas at about the same time. The dyad evolved with communication signals (1st picture) is perfectly able to reach target areas in the same time whereas it is clear that robots evolved, without signals (2nd picture), gets to the target area on its own.**[Ponticorvo, M., Miglino, O., Gigliotta, O. (in press). For Corvids together is better. A model of cooperation in evolutionary robotics, accepted in ECAL 2009 conference].**





NEW GENERATION OF EXPERIMENTS

WE TRAINED A DYAD OF ARTIFICIAL AGENTS (I.E. ROBOTS) WITH A "LOOSE-STRING"-LIKE TASK IN ORDER TO IDENTIFY THE MINIMAL COGNITIVE CAPABILITIES REQUIRED BY CORVIDS. IN THIS WAY IT SHOULD BE POSSIBLE TO UNDERSTAND AND PREDICT THE UNDERPINNING MECHANISMS OF THIS KIND OF COGNITIVE CAPABILITIES.

- DO ARTIFICIAL AGENTS CAN SOLVE THE TASK WITHOUT ANY COMMUNICATION ABILITIES ?
- DO THEY NECESSARILY NEED A COMMUNICATION CHANNEL?
- HOW MANY LEVEL OF COMMUNICATION EXIST ?
- IN ORDER TO COMMUNICATE, IS IT NECESSARY TO HAVE A COMMUNICATION CHANNEL OR IS IT SUFFICIENT TO SEE AND TAKE IN CONSIDERATION ACTIONS OF PARTNERS ?

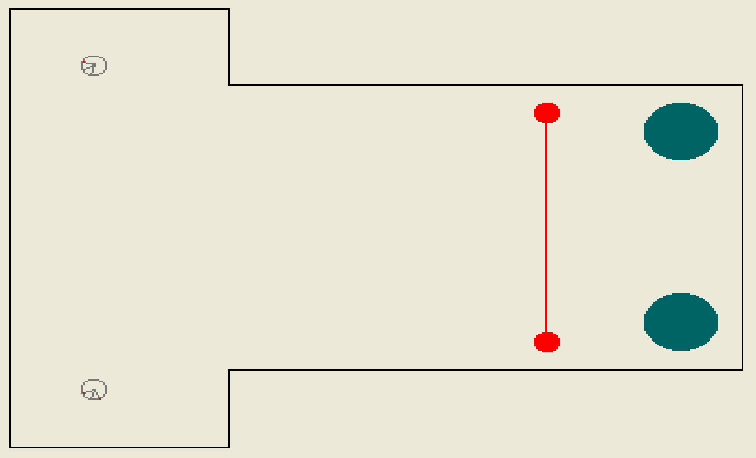
EXPERIMENTAL SETUP N.1

<u>PURPOUSE :</u> VERIFY THE POSSIBILITIES THAT A DYAD OF SIMULATED ROBOTS CONTROLLED BY A NEURAL NETWORK IS ABLE TO SOLVE A TASK EQUIVALENT TO "LOOSE-STRING" OF CORVIDS, BUT WITH AGENTS WHICH HAVE NO COMMUNICATION ABILITY.

<u>TASK :</u> TRY TO TAKE THE BAR UNTIL IT INTERSECTS THE TWO TARGET AREAS

CHARACTERISTICS OF THE TASK :

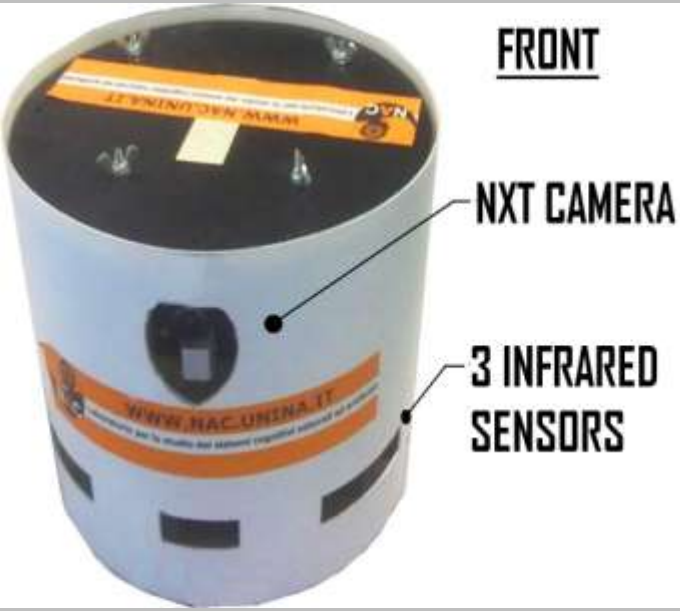
- ROBOTS CAN ONLY SEE THE BAR BUT CAN NOT SEE EACH OTHER
- ROBOTS PERCEIVE ONLY RED COLOR BY A NXT CAMERA MOUNTED IN THE FRONT OF ITS CHASSIS.



EXPERIMENTAL SETUP N.1

SIMULATED ROBOT :

- **NAC ROBOTS** BUILT WITH LEGO MINDSTORMS.
- 3 PROXIMITY INFRARED SENSORS .
- 1 NXT CAMERA
- 2 MOTORIZED WHEELS



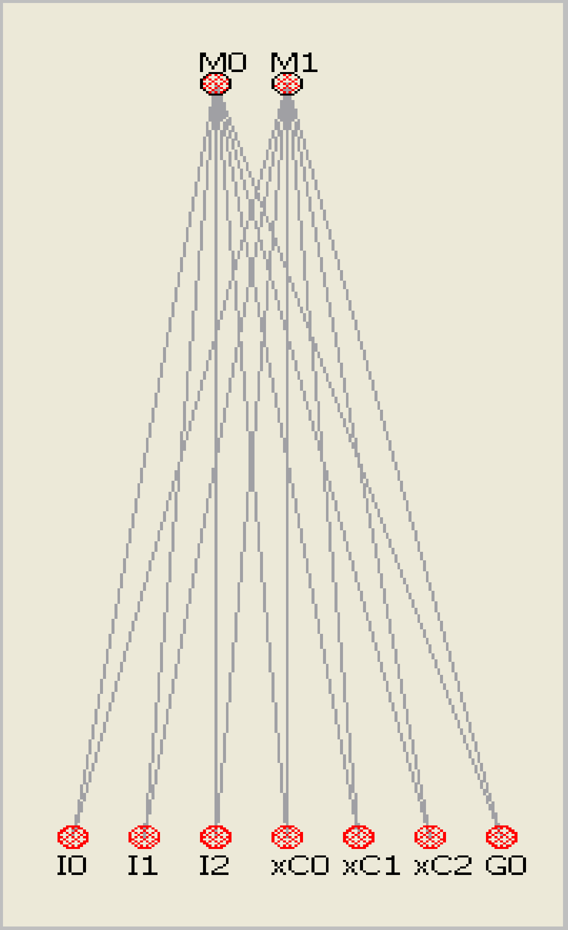
ENVIRONMENT :

- SQUARE ARENA OF ABOUT 80 X 160 CM.
- 1 MOBILE BAR.
- 2 LANDMARKS USED AS TARGET AREAS

EXPERIMENTAL SETUP N.1

CONTROL SYSTEM :

- **FEED-FORWARD NEURAL NETWORK WITHOUT HIDDEN LAYER (PERCEPTRON)**
- 3 INPUT NEURONS ENCODING INFRARED SIGNALS.
- 3 INPUT NEURONS ENCODING NXT CAM SIGNALS.
- 1 INPUT NEURON THAT RECEIVE GROUND SENSOR SIGNAL TO PERCEIVE LANDMARKS.
- 2 OUTPUT NEURONS CONTROLLING MOTOR SPEED OF TWO WHEELS.



EXPERIMENTAL SETUP N.1

EVOLUTIONARY ALGORITHM :

- **GENETIC ALGORITHM :** "RANK BASED" WITH SYNAPTIC WEIGHTS AND BIASES ENCODED INTO THE GENOTYPE
- **NUMBERO OF REPRODUCING INDIVIDUALS :** 20 (BEST IND.)
- **OFFSPRING :** 5 (OFFSPRING DERIVED FROM MUTATION)
- **NUMBER OF GENERATIONS :** 300
- **NUMBER OF EPOCHS :** 10 TRIAL
- **LIFETIME :** 3000 CYCLES (1 CYCLE = 100MS)
- **MUTATION RATE :** 2%

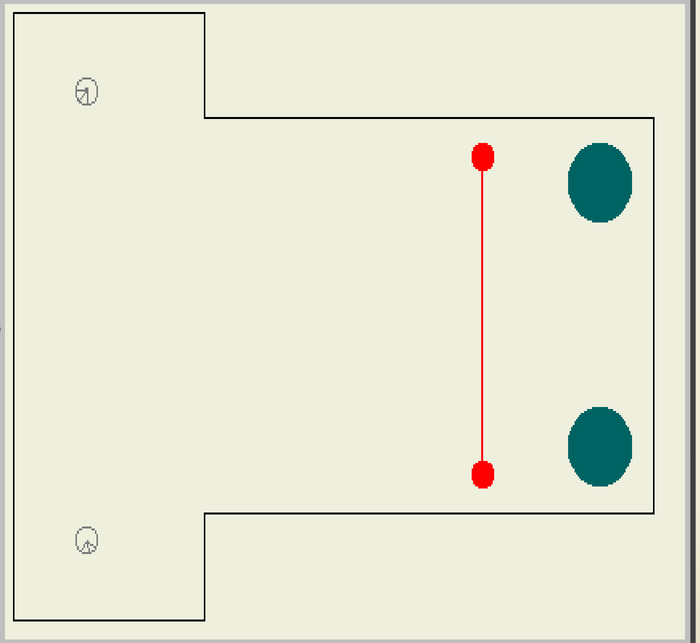
FITNESS FUNCTION :

- **FUNCTION :** SUM OF FITNESS SCORES OBTAINED AS FOLLOWS :
  a) **+1.0** if the bar intersects both target areas represented by landmarks, in a lifecycle t.
  b) **+0.0** otherwise.

EXPERIMENTAL SETUP N.1

RESULTS :

- By evolving robots for 10 replications we observed that they can solve the task employing an exclusively sensory-motor strategy
- **Strategy** : Robots rotate on themselves while they move forward. In this way they can reach the bar at about the same time. Timing of rotations and waiting are set by evolution.



Unexpected events such as in the video, determine delays because the robots have no way to synchronize.

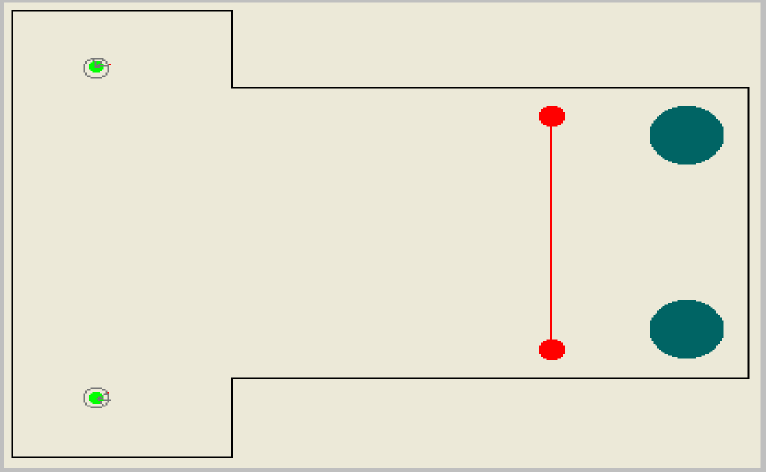
EXPERIMENTAL SETUP N.2

<u>PURPOUSE :</u> VERIFY THE POSSIBILITIES THAT A DYAD OF SIMULATED ROBOTS CONTROLLED BY A NEURAL NETWORK IS ABLE TO SOLVE A TASK EQUIVALENT TO "LOOSE-STRING" OF CORVIDS, BUT WITH AGENTS WHICH CAN SEE EACH OTHER.

<u>TASK :</u> TRY TO TAKE THE BAR UNTIL IT INTERSECTS THE TWO TARGET AREAS

CHARACTERISTICS OF THE TASK :

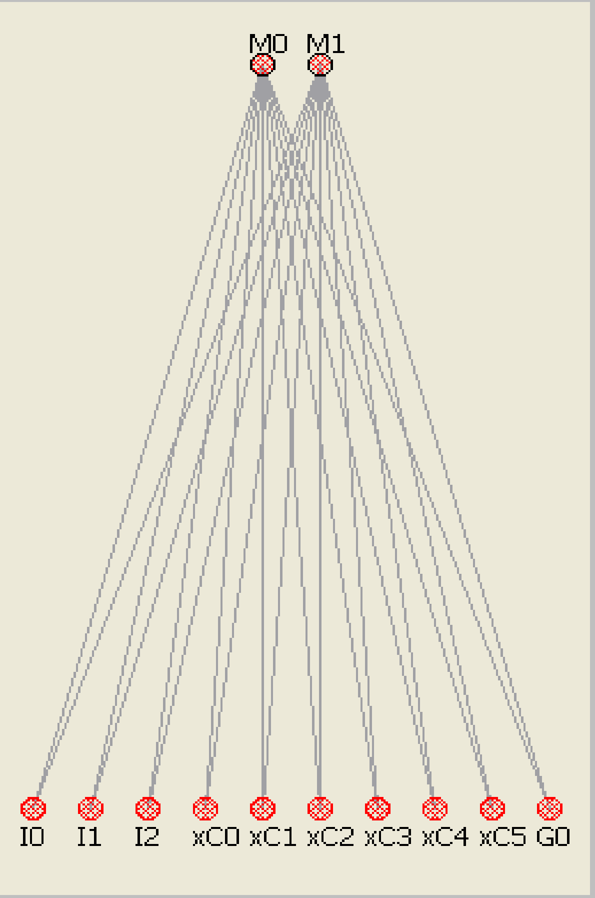
- ROBOTS CAN SEE THE BAR AND EACH OTHER
- ROBOTS PERCEIVE RED AND GREEN COLORS BY TWO NXT CAMERAS MOUNTED IN THE FRONT OF ITS CHASSIS.



EXPERIMENTAL SETUP N.2

ROBOT, ENVIRONMENT, CONTROL SYSTEM,EVOLUTIONARY ALGORITHM AND FITNESS

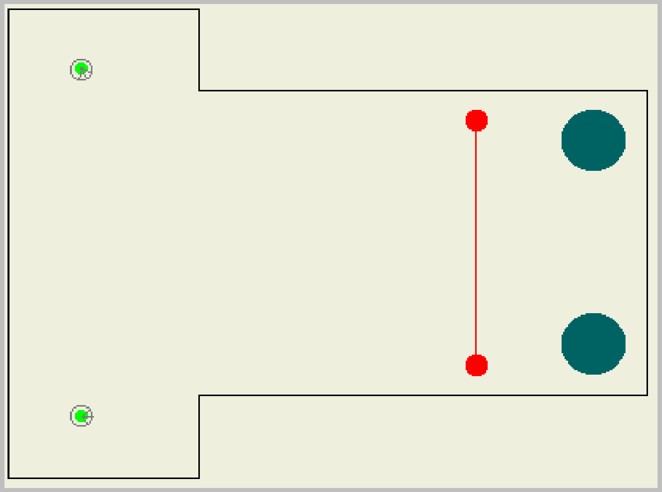
- **ROBOTS** HAVE AN NXT CAMERA MORE WHICH CAN DETECTS GREEN COLOR.
- **PERCEPTRON** HAS 3 NEURONS MORE (XC3, XC4, XC5) RELATED TO GREEN SENSITIVE NXT CAMERA.
- **GENETIC ALGORITHM** PARAMETERS ARE THE SAME OF SETUP N.1'S ALGORITHM.
- **FITNESS GENETIC** IS THE SAME OF THE FITNESS OF THE EXPERIMENTAL SETUP N.1

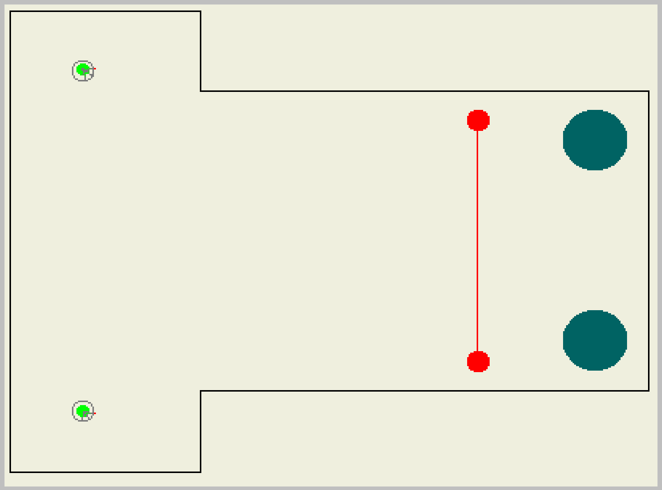


EXPERIMENTAL SETUP N.2

RESULTS :

- By evolving robots for 10 replications they show a complex strategy based on a “vision driven” form of communication.
- **Syncronization**: Robots rotate on themselves while they move forward, but now the timing of rotations is determined by the vision. Moreover they can syncronize by vision (**clip 1**).
- **Coordination :** Now robots can coordinate to select the right bar side for pushing, because they can see each other **(clip 2).** In setup n.1 they didn’t perform this kind of coordination.





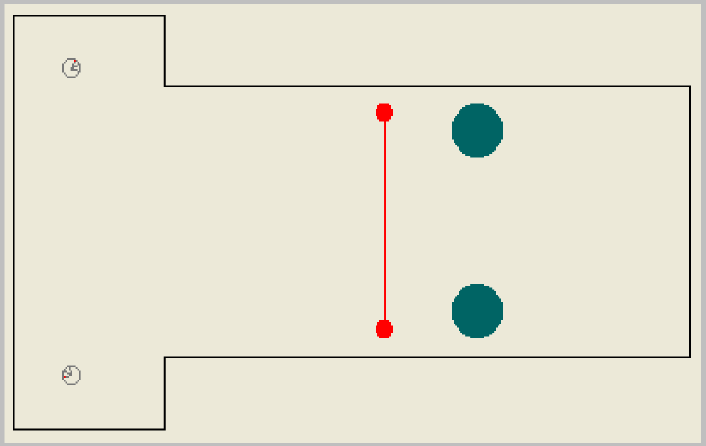
EXPERIMENTAL SETUP N.3

PURPOUSE : VERIFY THE POSSIBILITIES THAT A DYAD OF SIMULATED ROBOTS CONTROLLED BY A NEURAL NETWORK IS ABLE TO SOLVE A TASK EQUIVALENT TO "LOOSE-STRING" OF CORVIDS, BUT WITH AGENTS WHICH CAN EMPLOY A COMMUNICATION CHANNEL AND CANNOT SEE EACH OTHER.

TASK : TRY TO TAKE THE BAR UNTIL IT INTERSECTS THE TWO TARGET AREAS

CHARACTERISTICS OF THE TASK :

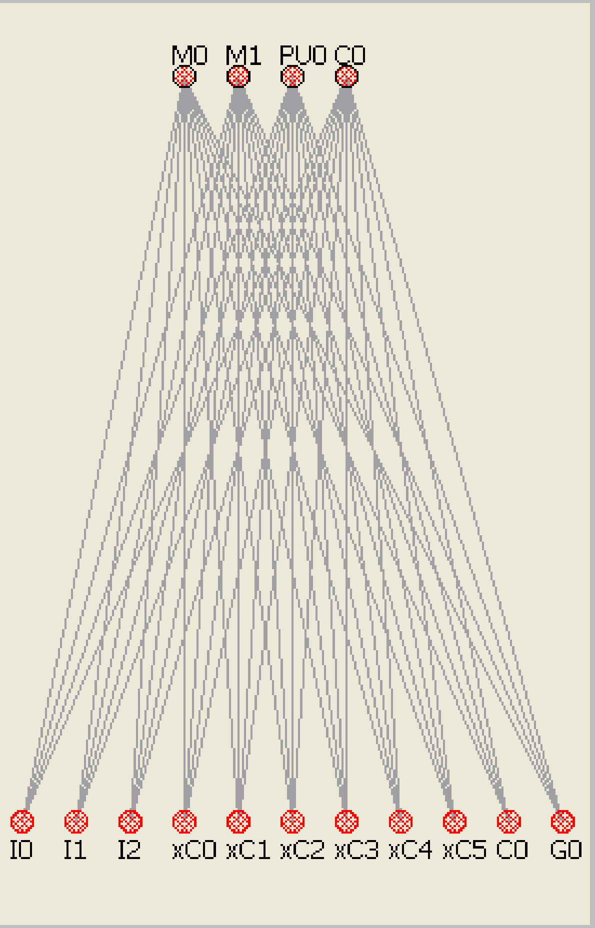
- ROBOTS CAN SEE ONLY THE BAR
- ROBOTS CAN EMIT A RADIO SIGNAL (BLUETOOTH) AND CAN RECEIVE THE SIGNAL FROM THE OTHER ROBOT.
- EACH ROBOT CAN PUSH THE BAR ONLY BY EMITTING A "PUSHING" SIGNAL THAT UNLOCK THE BAR.



EXPERIMENTAL SETUP N.3

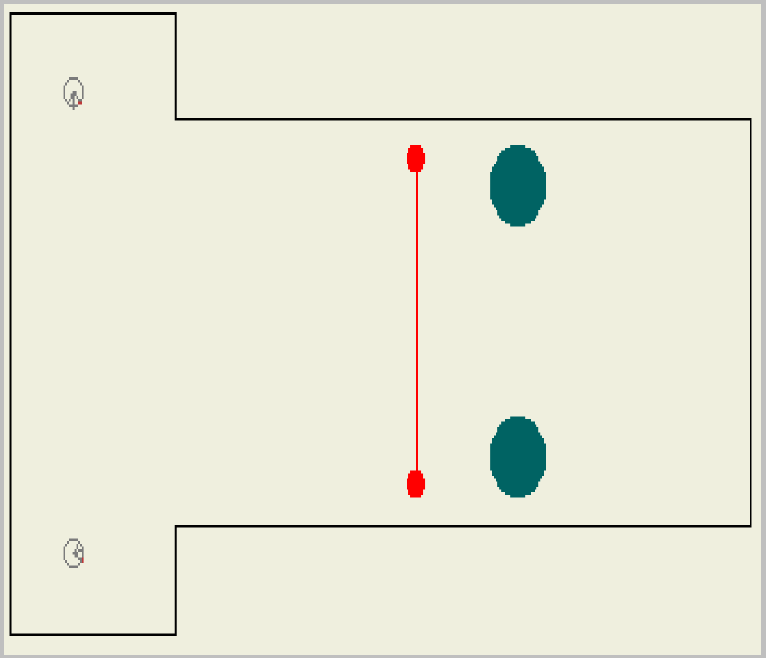
ROBOT, ENVIRONMENT, CONTROL SYSTEM,EVOLUTIONARY ALGORITHM AND FITNESS

- **ROBOTS** HAVE ONLY 1 NXT CAMERA WHICH DETECTS RED COLOR.
- **PERCEPTRON** HAS 1 OUTPUT THAT CONTROL RADIO COMMUNICATION OUTPUT (C0) AND 1 INPUT NEURON ENCODING COMMUNICATION INPUT(C0). MOREOVER PERCEPTRON HAS 1 OUTPUT NEURON (PU0) THAT CONTROL "PUSHING-UNIT". ROBOTS CAN PUSH THE BAR ONLY IF BOTH ROBOT'S "PUSHING-UNIT" ARE ACTIVE. OTHERWISE THE BAR IS BLOCKED.
- **GENETIC ALGORITHM** AND **FITNESS** ARE THE SAME OF SETUP N.1 AND N.2.



EXPERIMENTAL SETUP N.3

RESULTS :



- By evolving robots for 10 replications we observed emergence of a simple form of coomunication used by robots to syncronize them to push the bar.
- **Syncronization**: Unlike setup n.2 syncronizzation, in setup 3, is performed by communication and not by vision. In this way robots can arrive to the bar in the same time. If a robot is delayed (**see clip**), the other robot wait for the partner until it receive a specific signal that represent the robot is arrived.
- **Pushing unit :** When a robot wait for the other one, we observed that pushing unit is active. This means that the robot intends to move the bar, but it waits for the signal from the companion before push the bar.

CONCLUSIONS AND FUTURE DIRECTIONS

- IN THIS PRELIMINARY WORK WE HAVE INVESTIGATED ABOUT COMMUNICATION CABABILITIES OF NATURAL AND ARTFICIAL ORGANISMS.

- WE OBSERVED DIFFERENT LEVEL OF COMMUNICATION AND INDEPENDENCE BETWEEN INTENTION AND ACTIONS

NEXT STEPS

•TEST OTHER FORMS OF "LOOSE STRING" EXPERIMENT, FOR EXANPLE "CHOICE TEST".

• INVESTIGATE SISTEMATICALLY ON RELATION BETWEEN INFORMATION ABSENCE AND COMMUNICATION NEEDS OF NATURAL AND ARTIFICIAL ORGANISMS.

AKNOWLEDGEMENTS

Thank you for attention.

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